

Examining Associations between Childhood Asthma and Traffic Flow Using a Geographic Information System

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Using geographic information systems (GIS) and routinely collected data, we explored whether childhood residence near busy roads was associated with asthma in a low-income population in San Diego County, California. We examined the locations of residences of 5,996 children ≤ 14 years of age who were diagnosed with asthma in 1993 and compared them to a random control series of nonrespiratory diagnoses ($n = 2,284$). Locations of the children's residences were linked to traffic count data at streets within 550 ft. We also examined the number of medical care visits in 1993 for children with asthma to determine if the number of visits was related to traffic flow. Analysis of the distribution of cases and controls by quintiles and by the 90th, 95th, and 99th percentiles of traffic flow at the highest traffic street, nearest street, and total of all streets within a 550-ft buffer region did not show any significantly elevated odds ratios. However, among cases, those residing near high traffic flows (measured at the nearest street) were more likely than those residing near lower traffic flows to have two or more medical care visits for asthma than to have only one visit for asthma during the year. The results of this exploratory study suggest that higher traffic flows may be related to an increase in repeated medical visits for asthmatic children. Repeated exposure to particulate matter and other air pollutants from traffic exhaust may aggravate asthmatic symptoms in individuals already diagnosed with asthma. **Key words:** case-control, childhood asthma, geographic information system, GIS, Medi-Cal, traffic. *Environ Health Perspect* 107:761-767 (1999). [Online 10 August 1999]
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Asthma is the most common chronic disease among children and the most common diagnosis leading to childhood hospitalization in the United States (1). Air pollutants that are found near busy roads as a product of traffic exhaust, such as NO₂ and particulate matter, have been shown to be associated with respiratory illness in children (2,3).

Several studies conducted in the last 5 years have used proximity to traffic flow as a proxy for exposure to traffic exhaust. These studies found associations between traffic flow and increased risks of childhood hospital admissions (4), respiratory symptoms (5,6), and decreased lung function (7). In these studies, data on traffic flow were obtained by self-report (6) using the highest traffic volume in the school district (5), measuring distances from residences to streets on maps and assigning traffic density (7), and linking traffic flow data to residential postal zip codes (8).

We were interested in examining whether a childhood residence near busy roads was associated with asthma in a low-income population in San Diego County, California. We also wanted to determine whether a child's risk for multiple asthma-related medical care visits increased as a function of traffic flow in the study area. San Diego County was chosen due to the availability of comprehensive traffic information and because health data were available from an ongoing geographic information systems

(GIS) study of environmental, demographic, and health characteristics in the California/Baja California border region (9).

Recent availability of geocodable health data (ability to locate residences in space) and more widespread use of GIS give health researchers greater ability to link exposure information to individual addresses. We investigated whether GIS could be useful in linking traffic volume information to asthma cases and a random control series that were obtained from routinely collected billing information, which would provide a more accurate exposure assessment than linking asthma cases to average exposure values in an area, as is often done in an ecologic study design approach.

Methods

Health data. We obtained data on childhood asthma cases and controls from the Medi-Cal (California's Medicaid Program) paid claims database, maintained by the Medical Care Statistics Program of the California Department of Health Services (Sacramento, CA). This database contains information on all Medi-Cal beneficiaries in California. The Medi-Cal program pays for the health care of qualifying individuals on public assistance, those who are "medically needy" (blind, disabled, elderly), or those who are medically indigent. Data are collected by the month the Medi-Cal claim is paid, which may occur several months after the

claim is submitted. This large database acquires approximately 8 million records per month. Collected data items include the patient's address, date of birth, sex, race/ethnicity, medical diagnosis [based on the *International Classification of Diseases*, Revision 9 (ICD-9) code (10)], the date the patient was seen by their provider, and the type of medical visit (physician visit, inpatient, outpatient, or pharmacy).

For study cases ($n = 14,636$) we selected all claims paid between January 1993 and June 1994 with a diagnosis of asthma (ICD-9 code 493) in a child ≤ 14 years of age residing in any of three California counties: San Diego, Imperial, or Monterey. For study controls we selected an equivalent random sample ($n = 14,636$) of all claims paid during the same time period with any diagnoses in children ≤ 14 years of age. Because digital traffic flow data for 1993 were available only for San Diego County, we limited cases and controls to San Diego County residents ($n = 11,067$ for cases and 11,174 for controls). A total of 4,655 potential control records were for pharmacy visit claims. Because these records lacked ICD-9 coding to identify the claimant's type of illness, we excluded them from the control population to prevent including asthma cases among the controls. The remaining claim records were for physician, inpatient, or outpatient visits. After restricting the data to children who were seen by a provider in 1993, we were left with a total of 7,222 cases and 3,928 controls. Because a child who had more than one

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Medi-Cal claim during the year could be included more than once in the database, we used only data from each child's first visit of the year ($n = 7,053$ for cases and 3,902 for controls).

We geocoded cases and controls using ARC/INFO software (version 7.1; Environmental Systems Research Institute, Redlands, CA). A total of 5,996 (85.0%) cases and 3,323 (85.2%) controls were successfully address-matched to a 1:24,000 scale street network layer obtained from the San Diego Association of Governments (SANDAG; San Diego, CA) (11). Address matching was not possible for claim records that had post office box, incomplete, or non-San Diego County address information.

Controls were further excluded if they were already counted as cases ($n = 64$), had missing or miscoded diagnosis information ($n = 203$), or had medical diagnoses related to respiratory disease (ICD-9 460–519; $n = 754$) or neoplasms (ICD-9 140–239; $n = 18$). We removed those claims related to respiratory disease from the control series in order to exclude diagnoses such as asthma and bronchitis. Those with neoplasms were excluded because previous studies have found associations between traffic exhaust and childhood cancers (12). This left a total of 2,284 controls available for analysis. The final group of selected controls was similar in sex, race, and age to the pool of potential controls.

Traffic data. We obtained average daily traffic (ADT) flow data for 1993 for all roads in San Diego County from SANDAG (13). SANDAG maintains a complete ADT flow database that is linked to the 1:24,000 scale street network layer. The ADT values are calculated by local and county governments using traffic counters and are collected for nearly all the highways and major arterials in the county. A much smaller proportion of local roads is also measured. The ADT values for state highways and collector roads, obtained from the California Department of Transportation (CALTRANS), are incorporated into the SANDAG database. The ADT values are defined as the average number of cars per weekday and are calculated from a minimum of 48 hr of weekday traffic flow.

Census data. To identify a block group for each case and control residence, we linked each residence to SANDAG block group boundary layers. We used data from the 1990 U.S. Census (STF3 file) (14) to determine percentages of labor-force unemployment (for persons ≥ 16 years of age), childhood poverty, educational status, urban/rural status, median household income, and home heating fuel use for each block group. We defined childhood poverty as the percent of children < 18 years of age with a 1989 income below the poverty level. We defined

educational status as the percent of persons ≥ 18 years of age with less than a high school diploma. A block group was considered urban if 75% or more of the population resided inside an urbanized area. The percent of occupied households using electricity, utility gas, coal, and wood for home heating fuel was determined for each block group.

Data analysis. For each case and control residence, we constructed a 550-ft (168.8-m) radius circular buffer region around the geocoded residence location using ARC/INFO (Figure 1). Because an examination of several air emission dispersion models indicated 80–90% decay of pollutants between 492 and 656 ft (15,16), we chose a 550-ft buffer as an approximation of the exposure influence of traffic. All street segments with attributed ADT data were captured for each case and control within the buffered region. In this way we were able to link each study subject with the number of street segments having ADT data within the buffer region. For each study subject we were also able to determine the distance from the subject's residence to each street segment and the number of cars per day traveled on each street segment within the subject's buffered region.

We examined the differences in proportions by case-control status for 1990 census block group level variables and for individual level variables (sex, race/ethnicity, age, and visit type—physician visit, outpatient, or inpatient). We used Wilcoxon rank sum tests to assess the statistical significance of differences in average traffic volume for the street with the highest traffic volume within the buffer, the closest street to the residence, and for the sum of all streets within the 550-ft buffer region by case-control status. If two streets were equidistant from the residence, the street with the highest traffic volume was selected as the closest street [$n = 10$ (0.2%) for cases and $n = 2$ (0.2%) for controls]. We also calculated odds ratios (ORs) and 95% confidence intervals (CIs) (based on the traffic flow distribution for the controls) for each quintile of traffic flow and for the 90th, 95th, and 99th percentiles of flow for the three street classifications. We used multivariate logistic regression to compute odds ratios and 95% confidence intervals adjusted for potentially confounding variables (17). Models were run separately by sex. We used the Hosmer-Lemeshow test (18) to compute model fit.

Because pollutants disperse from the highway as a factor of distance and turbulence



Figure 1. Buffer (550 ft; 168.8 m) encircling cases and controls to capture traffic flow.

factors such as wind speed and atmospheric stability (4), we applied weights from two simple dispersion models to the traffic flow data. Most dispersion models assume that plumes of motor vehicle exhaust emissions, as they move downwind, spread in a Gaussian manner in vertical and horizontal directions. We used a model adapted by Pearson et al. (19), which assumes no wind and that pollutants are essentially inert and disperse from the source (Pearson model). This model uses a Gaussian probability distribution which assumes that 96% of the pollutants disperse at 500 ft. The model was expressed by

$$Y = \left(\frac{1}{0.4\sqrt{2\pi}} \right) e^{-\frac{0.5(D/500)^2}{(0.4)^2}},$$

where D is the distance from the street to the residence and Y is the weighting value.

For comparison, we also used a Gaussian curve dispersion model with assumptions of neutral wind stability, a wind speed of 1 m/sec, and a pollution concentration height of 1 m (Gaussian model) (20). Traffic at distances < 20 m from each case and control residence was weighted by 1.0 for this second model. Using weightings from these two models (Pearson and Gaussian models), we recalculated odds ratios and 95% confidence intervals for the three street classifications: a) the street with the highest traffic volume, b) the closest street to the residence, and c) at all streets within the 550-ft buffer region.

We also analyzed the relationship between case-control status and the actual distance from the residence to the closest street and the street with the highest traffic

flow (as opposed to weighting the traffic flow counts by distance). We computed odds ratios and 95% confidence intervals for case-control status at 100-ft intervals (0–100, 101–200, 201–300, 301–400 and > 400 feet) of the distance between the residence and the street.

In addition to analyzing the relationship between case-control locations and traffic data, we tested for spatial clustering of cases among the case-control locations (irrespective of proximity to traffic). We assessed the spatial pattern of masked data (perturbed points) using the Cuzick and Edwards test (21) (with a separate analysis by L. Waller and L. Zhu). This test compares the observed number of a case's nine nearest neighbors who are also cases among the set of case-control locations. A high number of cases among the nearest neighbors of other cases would suggest spatial case "clustering." To assess significance of the observed test statistic value, we randomly assigned the total number of cases to the case-control locations 200 times and calculated the statistic for each random assignment. This provided a simulation-based estimate of the test statistic distribution under the null hypothesis of no spatial pattern.

To examine whether traffic flow may be related to the frequency of medical care visits for asthma, we computed the number of physician, inpatient, and outpatient visits during 1993 for each case. The amount of average daily traffic (at the street with the highest traffic volume, at the closest street to the residence, and at all streets within the 550-ft buffer region) was compared for cases with two or more visits for asthma and for cases with only one visit during the year. We calculated the odds ratios and 95%

confidence intervals for each quintile of traffic flow (based on the traffic flow distribution for those with one visit), and for the 90th, 95th, and 99th percentiles for the three street classifications (highest, nearest, and total). We also analyzed the relationship between the number of each case's medical care visits for asthma and the actual distance from that child's residence to the nearest street, as well as the distance from the residence to the street with the highest traffic flow. We used SAS, Version 6.12 (22), and EPI-INFO, Version 5.01a (23), for all statistical analyses.

Results

Case-control analysis. Table 1 shows the distribution of ICD-9 codes among the controls. Approximately one-fourth of the controls had diagnoses for nervous system and sense organ diseases, primarily disorders of refraction (nearsightedness/farsightedness), conjunctiva disorders, ear infections, and hearing loss. Other large diagnostic categories included injuries (14%), ill-defined conditions (symptoms that point with "equal suspicion to two or more diseases or two or more systems of the body, without the necessary study to make a final diagnosis"; 10.9%), and contact with the health care system (V codes; 15.6%).

Tables 2 and 3 show the distribution of cases and controls by individual and census characteristics. Cases were more likely to be male and black, and less likely to be Hispanic. Cases were also older, more likely than controls to be seen in a physician's office, and less likely than controls to have hospital outpatient visits. Cases and controls had similar block group census characteristics such as unemployment, poverty level, and

Table 1. Distribution of controls by *International Classification of Diseases*, Revision 9 (ICD-9) code.^a

| ICD-9 code | No. (%) |
|--|---------------|
| Total | 2,284 (100.0) |
| Contact with health care system (V codes) ^b | 357 (15.6) |
| Infectious/parasitic disease (001–139) | 183 (8.0) |
| Endocrine/nutritional/metabolic disorders (240–289) | 62 (2.7) |
| Mental disorders (290–319) | 53 (2.3) |
| Nervous system and sense organ diseases (320–389) | 551 (24.1) |
| Circulatory system (390–459) | 10 (0.4) |
| Digestive system (520–579) | 154 (6.7) |
| Genitourinary system (580–629) | 52 (2.3) |
| Complications of pregnancy, childbirth (630–676) | 7 (0.3) |
| Skin disease (680–709) | 159 (7.0) |
| Musculoskeletal disease (710–739) | 60 (2.6) |
| Congenital anomalies (740–759) | 34 (1.5) |
| Perinatal period (760–779) | 32 (1.4) |
| Ill-defined conditions (780–799) | 249 (10.9) |
| Injury (800–999) | 321 (14.1) |

^aFrom 1993 California Department of Health Services Medi-Cal paid claims data for San Diego County.

^bIncludes communicable disease, family history, reproductive problems, specific procedures, etc.

Table 2. Individual characteristics of asthma cases and controls.^a

| | Cases | | Controls | | OR | CI |
|------------------|-------|---------|----------|---------|------|------------|
| | No. | Percent | No. | Percent | | |
| Total | 5,996 | 100.0 | 2,284 | 100.0 | | |
| Sex | | | | | | |
| Male | 3,595 | 60.0 | 1,160 | 50.8 | 1.45 | 1.32–1.60 |
| Female | 2,401 | 40.0 | 1,124 | 49.2 | 1.0 | ref |
| Race/ethnicity | | | | | | |
| White | 1,789 | 29.8 | 632 | 27.7 | 1.0 | ref |
| Hispanic | 2,251 | 37.5 | 1,182 | 51.8 | 0.67 | 0.60–0.76 |
| Black | 1,254 | 20.9 | 303 | 13.3 | 1.46 | 1.25–1.71 |
| Other | 674 | 11.2 | 144 | 6.3 | 1.65 | 1.35–2.03 |
| Unknown | 28 | 0.5 | 23 | 1.0 | 0.43 | 0.24–0.78 |
| Age | | | | | | |
| < 1 year | 288 | 4.8 | 322 | 14.1 | 1.0 | ref |
| 1–4 years | 2,466 | 41.1 | 882 | 38.6 | 3.13 | 2.61–3.74 |
| 5–14 years | 3,242 | 54.1 | 1,080 | 47.3 | 3.36 | 2.81–4.01 |
| Type of visit | | | | | | |
| Outpatient | 1,326 | 22.1 | 992 | 43.4 | 1.0 | ref |
| Inpatient | 107 | 1.8 | 12 | 0.5 | 6.67 | 3.55–12.81 |
| Physician office | 4,563 | 76.1 | 1,280 | 56.0 | 2.67 | 2.40–2.96 |

Abbreviations: CI, 95% confidence interval; OR, odds ratio; ref, reference.

^aFrom 1993 California Department of Health Services Medi-Cal paid claims data for San Diego County.

household income (Table 3), confirming similar low socioeconomic status at the neighborhood level. We observed no significant differences between cases and controls in the census block group prevalence of home heating methods.

Out of all cases and controls, approximately 75% lived within 550 ft of a street with traffic flow data (Table 4). Controls were more likely than cases to live closer to the street with the highest traffic flow within the 550-ft buffer region ($p < 0.01$) and were more likely to have higher average traffic volume at the nearest street ($p = 0.03$) (Table 4). We saw no statistically significant difference between cases and controls in average traffic volume of the street with the highest traffic flow or in average traffic volume at all streets combined in the 550-ft buffer region. Bivariate analysis of the traffic volume variables and child's age, race, sex, type of visit, and urban status (which varied by case-control status) showed that race, type of visit, and urban status varied by traffic volume and were therefore treated as potentially confounding variables in multivariate analysis.

The analysis of case and control distribution by quintiles and at the 90th, 95th, and 99th percentiles of traffic flow at the highest, nearest, and total of all streets within the 50-ft buffer region did not show any significantly elevated odds ratios (Table 5). This did not change after controlling for race, type of visit, and urban/rural status (Table 5). No significant differences by sex were observed in sex-specific multivariate analysis. Results of the Hosmer-Lemeshow test showed good model fit for the quintile analysis [highest street: goodness of fit (GOF) statistic = 7.59, $p = 0.47$; nearest street: GOF statistic = 7.0, $p = 0.54$; total streets: GOF statistic = 3.57, $p = 0.89$]. Weighting the nearest or highest traffic volumes by the Pearson or Gaussian decay curve models did not result in any meaningful changes in the odds ratios (not shown). Analysis of the distribution of cases and controls with distance to the nearest street or to the street with the highest traffic flow did not show any elevated odds ratios or dose-response patterns.

Because controls with injury diagnoses ($n = 321$) may have had traffic-associated injuries related to road proximity, all analyses were repeated without these controls. We noted no significant changes in the odds ratios.

Evaluation of spatial autocorrelation revealed evidence of spatial patterns within the set of nine nearest neighbors of the cases (Cuzick and Edwards test statistic = 18,072, $p = 0.005$). While the results indicate some clustering of cases, the logistic regression analysis indicates that this pattern is not associated with traffic volume (i.e., clustering of cases is not limited to areas of high traffic volume).

Table 3. Census block group characteristics of asthma cases and controls.^a

| | Cases ($n = 5,996$) Mean \pm SD | Controls ($n = 2,284$) Mean \pm SD |
|--|--|---|
| Percent unemployed in labor force (≥ 16 years of age) | 9.0 \pm 5.1 | 8.7 \pm 5.3 |
| Percent children < 18 years with 1989 income below poverty level | 27.2 \pm 19.1 | 27.3 \pm 19.3 |
| Percent persons ≥ 18 years with a high school diploma | 31.4 \pm 16.0 | 31.9 \pm 16.6 |
| Percent of households using home heating fuel | | |
| Electricity | 29.5 \pm 18.3 | 30.2 \pm 18.5 |
| Utility gas | 65.3 \pm 19.9 | 64.0 \pm 20.4 |
| Coal | 0.01 \pm 0.1 | 0.01 \pm 0.1 |
| Wood | 1.0 \pm 2.9 | 1.2 \pm 3.4 |
| Median household income (\$) | 27,319 \pm 10,848 | 27,410 \pm 10,741 |
| Urban ^b | | |
| Yes | 5,880 (98.1) | 2,219 (97.2) |
| No | 116 (1.9) | 65 (2.9) |
| Total | 5,996 (100.0) | 2,284 (100.0) |

Abbreviations: SD, standard deviation.

^aFrom 1993 California Department of Health Services Medi-Cal paid claims data for San Diego County. ^b $\geq 75\%$ of the population lives inside urbanized area; values are shown as number (percent).

Table 4. Traffic flow characteristics.^a

| | Cases ($n = 5,996$) | | Controls ($n = 2,284$) | | p-Value (χ^2 or Wilcoxon rank sum) |
|---|-----------------------|-------------|--------------------------|-------------|--|
| | N | (%) | N | (%) | |
| Street with traffic flow data within 550 feet of residence | | | | | |
| Yes | 4,484 | (74.8) | 1,748 | (76.5) | |
| No | 1,512 | (25.2) | 536 | (23.5) | NS |
| Average number of attributed streets within 550 ft | | 2.21 | | 2.24 | NS |
| Average distance from residence to street with highest traffic flow (ft) | | 281.7 | | 269.2 | < 0.01 |
| Average distance from residence to nearest street with traffic flow data (ft) | | 200.8 | | 203.9 | NS |
| Traffic volume at street with highest traffic flow (cars/day) | | | | | |
| Average | | 26,477 | | 25,912 | NS |
| Median | | 15,471 | | 15,600 | |
| Range | | 500–239,800 | | 400–213,000 | |
| Traffic volume at nearest street with traffic flow data (cars/day) | | | | | |
| Average | | 16,645 | | 17,464 | 0.03 |
| Median | | 10,600 | | 11,400 | |
| Range | | 500–239,800 | | 400–205,300 | |
| Traffic volume at all streets within 550 ft (cars/day) | | | | | |
| Average | | 42,880 | | 41,497 | NS |
| Median | | 21,950 | | 19,800 | |
| Range | | 500–729,200 | | 400–775,000 | |

NS, not statistically significant.

^aFrom 1993 California Department of Health Services Medi-Cal paid claims data for San Diego County.

Visit analysis. Of all cases that had traffic count data within 550 ft of their residences, 97.8% ($n = 4,385$) had only one medical care visit for asthma during the year, whereas 2.2% ($n = 99$) had two or three visits during the year. Those who had two or three visits were more likely than those with only one visit to be Hispanic (49.5 vs. 39.9%), to be male (67.7 vs. 59.1%), to have an outpatient hospital visit for asthma (36.4 vs. 22.1%), and to have fewer physician visits (61.6 vs. 76.1%). None of the cases with more than one medical visit had a change of address during the year.

Analysis of traffic flow quintiles on streets within 550 ft of the residence showed that children with two or more medical care visits

were more likely to have higher traffic flows at the nearest street than were children with only one visit (Table 6). Although there were elevated odds ratios at each traffic flow quintile, only the second quintile was statistically significant (5,501–9,000 cars/day vs. $< 5,500$ cars/day; OR = 2.14; 95% CI, 1.06–4.39). Adjustment for race (which was associated with the number of medical care visits and traffic volume among the cases) resulted in slight increases in the point estimates of the odds ratios (Table 6). Additional control for the type of medical care visit did not significantly change the magnitude of the odds ratios. The odds of a case having two or more medical visits (compared to one visit) was almost three times higher for individuals with

Table 5. Crude and adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for asthma for children 14 years of age and younger by quintiles of traffic flow.^a

| Traffic flow (cars/day) | Case (n) | Control (n) | Crude OR (CI) | Adjusted OR ^b (CI) |
|-------------------------------------|----------|-------------|------------------|-------------------------------|
| At nearest street | | | | |
| 1st quintile (ref) ($\leq 5,800$) | 969 | 352 | 1.0 | 1.0 |
| 2nd quintile (5,801–9,400) | 1,013 | 367 | 1.00 (0.84–1.19) | 0.93 (0.78–1.11) |
| 3rd quintile (9,401–14,400) | 864 | 339 | 0.93 (0.77–1.11) | 0.82 (0.68–0.98) |
| 4th quintile (14,401–22,400) | 779 | 346 | 0.82 (0.68–0.98) | 0.76 (0.63–0.91) |
| 5th quintile ($> 22,400$) | 859 | 349 | 0.89 (0.75–1.07) | 0.79 (0.66–0.95) |
| 90th percentile ($> 27,900$) | 434 | 174 | 0.91 (0.73–1.13) | 0.80 (0.64–1.00) |
| 95th percentile ($> 40,200$) | 231 | 87 | 0.96 (0.73–1.28) | 0.92 (0.69–1.22) |
| 99th percentile ($> 167,700$) | 41 | 13 | 1.15 (0.59–2.28) | 0.90 (0.47–1.74) |
| At highest street | | | | |
| 1st quintile (ref) ($\leq 8,200$) | 988 | 353 | 1.0 | 1.0 |
| 2nd quintile (8,201–12,500) | 886 | 352 | 0.90 (0.75–1.07) | 0.84 (0.70–1.01) |
| 3rd quintile (12,501–18,000) | 785 | 351 | 0.80 (0.67–0.96) | 0.76 (0.64–0.92) |
| 4th quintile (18,001–26,400) | 876 | 348 | 0.90 (0.75–1.07) | 0.85 (0.71–1.02) |
| 5th quintile ($> 26,400$) | 949 | 349 | 0.97 (0.81–1.16) | 0.89 (0.75–1.07) |
| 90th percentile ($> 43,200$) | 490 | 172 | 1.02 (0.82–1.27) | 0.99 (0.80–1.24) |
| 95th percentile ($> 127,400$) | 209 | 86 | 0.87 (0.65–1.16) | 0.82 (0.62–1.10) |
| 99th percentile ($> 195,400$) | 46 | 17 | 0.97 (0.53–1.78) | 0.68 (0.38–1.22) |
| Sum of all streets | | | | |
| 1st quintile (ref) ($\leq 9,100$) | 954 | 361 | 1.0 | 1.0 |
| 2nd quintile (9,101–16,700) | 813 | 343 | 0.90 (0.75–1.07) | 0.83 (0.69–1.00) |
| 3rd quintile (16,701–25,000) | 722 | 347 | 0.79 (0.66–0.94) | 0.76 (0.63–0.91) |
| 4th quintile (25,001–50,100) | 998 | 351 | 1.08 (0.91–1.28) | 1.00 (0.83–1.19) |
| 5th quintile ($> 50,100$) | 997 | 346 | 1.09 (0.91–1.30) | 1.05 (0.88–1.26) |
| 90th percentile ($> 90,500$) | 466 | 175 | 1.01 (0.81–1.25) | 0.98 (0.79–1.22) |
| 95th percentile ($> 161,400$) | 251 | 87 | 1.09 (0.82–1.45) | 1.06 (0.80–1.41) |
| 99th percentile ($> 366,000$) | 48 | 17 | 1.07 (0.59–1.96) | 1.02 (0.57–1.82) |

ref, reference.

^aFrom 1993 California Department of Health Services Medi-Cal paid claims data for San Diego County. ^bControlling for race (Hispanic, black, other, unknown vs. white), medical visit type, (inpatient/outpatient vs. physician visit) and urban/rural status (urban vs. rural).**Table 6.** Crude and adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for two or more medical care visits versus one visit for cases for children 14 years of age and younger.^a

| Traffic flow (cars/day) | N | | Crude OR (CI) | Adjusted OR ^b (CI) |
|------------------------------|---------------|---------|--------------------------------|----------------------------------|
| | 2 or 3 visits | 1 visit | | |
| On nearest street | | | | |
| 1st quintile (ref) (≤ 5,500) | 13 | 896 | 1.0 | 1.0 |
| 2nd quintile (5,500–9,000) | 28 | 902 | 2.14 (1.06–4.39) | 2.14 (1.10–4.16) |
| 3rd quintile (9,001–13,000) | 19 | 840 | 1.56 (0.73–3.36) | 1.64 (0.81–3.35) |
| 4th quintile (13,001–21,200) | 17 | 875 | 1.34 (0.61–2.94) | 1.37 (0.66–2.84) |
| 5th quintile (> 21,200) | 22 | 872 | 1.74 (0.83–3.67) | 1.85 (0.92–3.71) |
| 90th percentile (> 27,500) | 11 | 434 | 1.75 (0.72–4.19) | 1.86 (0.82–4.18) |
| 95th percentile (> 41,000) | 9 | 215 | 2.89 (1.07–7.40) | 2.91 (1.23–6.91) |
| 99th percentile (> 161,000) | 2 | 43 | 3.21 (0.34–14.83) ^c | 3.58 (0.78–16.44) |

Goodness-of-fit statistic for adjusted model = 2.25, $p = 0.94$.^aFrom 1993 California Department of Health Services Medi-Cal paid claims data for San Diego County. ^bControlling for race (Hispanic, black, other, unknown vs. white). ^cExact confidence limits.

traffic flow greater than 41,000 cars/day (95th percentile) at the nearest street (OR = 2.89; 95% CI, 1.07–7.40).

We noted increasing risks of multiple medical care visits at the 90th, 95th, and 99th percentiles of traffic volume, although confidence intervals were wide due to the small number of cases with multiple medical care visits. Analysis of traffic flow quintiles for the highest and sum of all streets did not result in any statistically significant differences in cases by number of visits (not shown). We found no dose-response relationship for the analysis of medical visit status with distance to the nearest street or to the street with the highest traffic flow.

Analysis of medical visit status of cases by traffic flow for boys and girls separately showed that girls had significantly higher risks than boys for multiple medical care visits associated with traffic flow (Table 7). We observed that the higher risks associated with the 90th, 95th, and 99th percentiles of traffic volume were almost entirely driven by the female population, with odds ratios of 3.82, 7.89, and 18.82, respectively.

Discussion

In this study we found no evidence of increased asthma risk with higher traffic counts near children's residences, even after distance weighting traffic counts using

pollution dispersion models and controlling for potential confounders in a multivariate logistic regression model. However, among children diagnosed with asthma, we found that the number of medical care visits increased with higher traffic counts of nearest streets, particularly at the 90th, 95th, and 99th percentiles. These findings are consistent with asthma literature, which classifies air pollution as a contributing factor rather than a causal factor to asthma development (24). Respiratory irritants such as SO₂, NO₂, and particulate matter, which are products of traffic exhaust, can cause respiratory irritation and have been shown to exacerbate asthmatic symptoms, but have not been thought to directly influence asthma prevalence (24). Shima and Adachi (25) found higher serum hyaluronate levels (thought to be a biomarker of lung damage) in children in Japan who live near busy roads, as compared to those who lived farther away, but only among children who already had elevated IgE levels. This suggests that exposure to automobile exhaust may be particularly damaging to children already suffering from atopic illness.

We found an elevated risk of increased medical care visits among asthmatic children at the second quintile (5,500 cars/day) of traffic flow, but no further dose-response effect until the 95th percentile (41,000 cars/day). One explanation could be that exhaust fumes from traffic have a step-type threshold effect that was reached at the second quintile of exposure. This phenomenon has also been seen in children of smoking mothers for whom no increased incidence of asthma was noted until the mother smoked 10 or more cigarettes per day (26). Because children in our study were from a low-income urban area, baseline exposures for most subjects were relatively high.

When examining the risk of multiple medical care visits for asthma with traffic flow, we found that girls had significantly higher risks than boys at the highest percentiles of traffic flow (90th, 95th, and 99th). This finding is similar to that of Oosterlee et al. (27), who found that girls had higher risks of chronic respiratory symptoms than boys among those living near streets with high traffic flows in the Netherlands. Higher risks of decreased lung function associated with residence near major roads were also found in girls by Brunekreef et al. (7). Comparison of our results in California with studies done in the Netherlands should be made with caution because of differences in types of vehicle emissions and emission controls. In a recent study by Peters et al. (28), ozone exposure was found to be related to decreased lung function in children with asthma, primarily in girls. Although boys have been found to have

Table 7. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for more than two versus one medical care visit for cases by traffic volume on nearest street, by sex, for children ≤ 14 years of age.^a

| Traffic flow (cars/day) | Adjusted OR ^b (CI) boys | Adjusted OR ^b (CI) girls |
|------------------------------|---------------------------------------|--|
| At nearest street | | |
| 1st quintile (ref) (≤ 5,500) | 1.0 | 1.0 |
| 2nd quintile (5,501–9,000) | 1.51 (0.67–3.40) | 4.21 (1.19–14.90) |
| 3rd quintile (9,001–13,000) | 1.73 (0.77–3.90) | 1.36 (0.30–6.13) |
| 4th quintile (13,001–21,200) | 1.28 (0.55–3.01) | 1.64 (0.39–6.94) |
| 5th quintile (> 21,200) | 1.62 (0.72–3.65) | 2.51 (0.64–9.84) |
| 90th percentile (> 27,500) | 1.27 (0.46–3.54) | 3.82 (0.90–16.24) |
| 95th percentile (> 41,000) | 1.56 (0.48–5.06) | 7.89 (1.84–33.75) |
| 99th percentile (> 161,000) | NA ^c | 18.82 (2.85–124.27) |

Abbreviations: NA, not available; ref, reference.

^aFrom 1993 California Department of Health Services Medi-Cal paid claims data for San Diego County. ^bControlling for race (Hispanic, black, other, unknown vs. white). ^cInsufficient sample size.

higher prevalences of asthma and may be at higher risk of respiratory illness (29), Peters et al. (28) suggest that girls with asthma may be more affected by pollution because of sex-related differences in rates of growth in height and maximum lung size (with girls achieving this earlier than boys), which may affect their response to air pollutants.

Although we found evidence of increased number of asthma-related medical care visits with higher traffic, it is not clear if repeat visits are a marker of increased severity (or number) of asthmatic symptoms or of more comprehensive patient care. However, because children in this low-income population are less likely to have routine medical care, they may be at higher risk of asthma exacerbation due to air pollution than non-poor populations (30).

In this case-control study, we used GIS to facilitate our analysis of childhood residence and traffic flows. The GIS allowed quick linkage of traffic count information to geocoded addresses. Further, the GIS facilitated efficient computation of traffic counts at the nearest street to the residence of the case control and at the street with the highest traffic, and summed the total traffic count at all streets within a 550-ft buffer area. By providing individual-level estimates, this method results in less exposure misclassification than applying average exposure values in an area using an ecologic study design. Additionally, because we did not obtain exposure information via questionnaire or self-report, this study was not subject to information bias that could explain our results. Because we lacked information on time-activity patterns, we were unable to determine if the children were exposed to traffic exhaust at other locations, such as schools and day-care center playgrounds. This potential misclassification is likely to be random with respect to case-control status and therefore would result in biasing our risk estimates toward the null.

We used traffic counts as a proxy for vehicle exhaust, and weighted the counts as a function of the distance from the child's

residence to the roadway. We did not model particulate matter or other constituents of traffic exhaust from traffic counts, as performed by Buckeridge et al. (31) in a study in southeast Toronto, Ontario, Canada. We lacked the necessary data for vehicle exhaust pollutant modeling such as vehicle type and the number of traffic stops. Analysis of aerial photos, as performed by Buckeridge et al. (31), would be useful in obtaining information on the number of lanes in a street and traffic stops.

We were limited in this study by the number of covariates, which could potentially confound the relationship between traffic and asthma risk. In particular, we lacked information on secondhand smoke exposure and residence history. If cases who lived near busier roads were more likely to have household members who smoked than cases who lived near less busy roads, then failure to control for smoking could have resulted in a spurious positive finding for increased risk of medical care visits with higher traffic counts. However, no difference in passive smoke exposure was found in populations living near busy and quiet roads in the Netherlands (27), nor was any relationship found between smoking status and distance from the residence to the road in a case-control study of 7,299 patients in East London, United Kingdom (8).

We lacked information on residence history, thus, we were unable to ascertain the duration of exposure for the case-control analysis. Oosterlee et al. (27) reported that among those who lived near busy streets, families of asthmatic children had lived at their present addresses for shorter times than families with nonasthmatic children. If this selective migration also operated in our study population, the increased risk we found for multiple medical visits and traffic flow may have been underestimated.

Elevated levels of ambient air pollutants, which were not assessed in this study, may increase the risk of asthma exacerbation (32). Delfino et al. (33) found a 25% increase in

daily asthma symptoms for 12 subjects with a 90th percentile (25 ppb) increase in personal ozone measurements in San Diego during 1993. From 1983 to 1994, maximum levels of ambient ozone levels decreased in San Diego County (from 280 to 150 ppb), whereas maximum levels of particulate matter (< 10 µm in diameter) more than tripled (from 38 to 129 mg/m³) during 1984–1994 (34). Concurrently, age-adjusted childhood asthma hospitalization rates decreased 9% annually in the county from 1983 to 1994 (34). Use of data from Medi-Cal, which includes both inpatient and outpatient visits to define individual cases and controls, is an improvement over studies of area hospitalization rates. Hospitalizations for asthma occur in acute cases; therefore, moderate or mild asthma events may be missed.

We found evidence of spatial clustering for asthma cases in this population, although not near busy roads. Asthma case clustering could be due to the increased asthma risk occurring in families or to some unknown geographic clustered environmental factor such as cockroach allergens (35). Because of the limited availability of study covariates, we were unable to fully explore the reasons for the spatial patterns of asthma found in this low-income area.

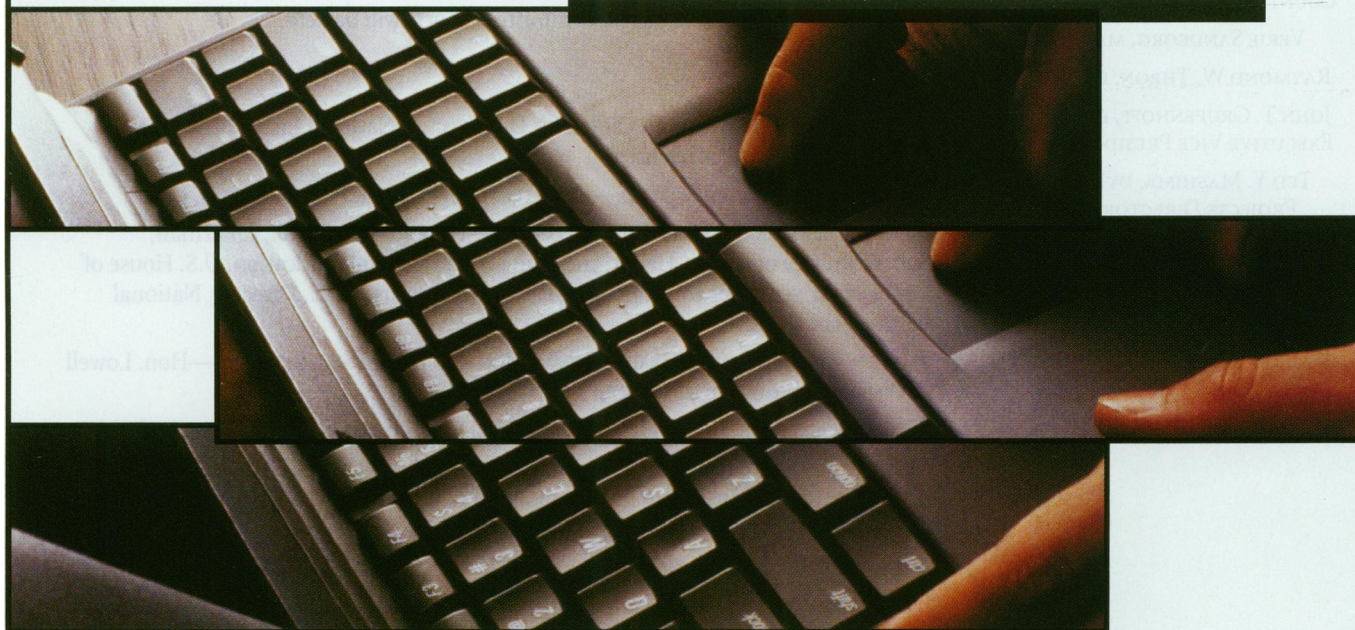
In summary, in this study we found evidence that asthmatic children living near busy roads may have an increased risk of repeated medical care visits, as compared to asthmatic children living near lower traffic flows. This suggests that higher traffic flows may be related to an increase in severity or number of asthmatic symptoms requiring repeated medical visits in asthmatic children. Repeated exposure to particulate matter and other air pollutants from traffic exhaust may aggravate asthmatic symptoms in individuals already diagnosed with asthma. Although we found no relationship between traffic flow and the initiation of asthma, this finding should be explored further in studies with more refined measures of exposure.

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